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Aquatic Ecotoxicology of the Pyrethroid Insecticide Lambda-cyhalothrin: Considerations for Higher-Tier Aquatic Risk Assessment†

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Abstract: Preliminary risk characterisation for the pyrethroid insecticide lambda-cyhalothrin identifies potential concerns for fish and aquatic invertebrates. Here we describe additional ecotoxicological studies for lambda-cyhalothrin generated to refine the aquatic risk assessment. These include tests conducted under more realistic exposure conditions (i.e. accounting for the rapid adsorption of lambda-cyhalothrin to sediments), studies on sediment toxicity and bioavailability, tests on a range of fish and invertebrate species in order to characterise sensitivity distributions, and field studies which have examined effects on invertebrate communities and fish populations under semi-natural conditions. Fish are generally less sensitive to lambda-cyhalothrin than are aquatic invertebrates, and fish species tend to be similar to each other in their sensitivities. Adsorption of lambda-cyhalothrin reduces exposure and hence the apparent toxicity of the compound to fish, and under field conditions no adverse effects on fish have been observed even at concentrations approaching the water solubility. For aquatic invertebrates, there is a wider range of sensitivities, with the Crustacea and Insecta predictably being the more sensitive taxa. Again, adsorption reduces the exposure of the chemical, and under field conditions no ecologically adverse effects have been observed at concentrations of *c.*0·02 μg litre^{-1}. © 1998 Society of Chemical Industry

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Key words: lambda-cyhalothrin; aquatic ecotoxicology; risk assessment; bioavailability

1 INTRODUCTION

Risk assessment of pesticides should include considerations of risks and benefits. The synthetic pyrethroid insecticides offer significant benefits because they provide highly efficacious control of arthropod pests at low use rates, have generally low toxicity to birds and mammals, and present low risks to applicators. However, concerns have been raised regarding potential risks to aquatic organisms (particularly fish and aquatic arthropods) due to the high inherent toxicity of these compounds demonstrated in standard, clean-water, laboratory studies.[1,2] In this paper, we review the aquatic ecotoxicology of the pyrethroid, lambda-cyhalothrin (a 1 + 1 by mass mixture of (*R*)-α-cyano-3-phenoxybenzyl (*Z*)-(1*S*)-*cis*-3-(2-chloro-3,3,3-trifluoroprop-1-enyl)-2,2-dimethylcyclopropanecarboxylate and (*S*)-α-cyano-3-phenoxybenzyl (*Z*)-(1*R*)-*cis*-3-(2-chloro-3,3,3-trifluoroprop-1-enyl)-2,2-dimethylcyclopropanecarboxylate) and describe additional aquatic eco-

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toxicological data that have been developed to refine the aquatic risk assessment.

Aquatic risk assessment for pesticides in the European Union (EU) includes a number of 'tiers' in which worst-case assumptions of the effect and exposure concentrations are progressively refined.[3] Put simply, at the first EU risk assessment tier, if predicted environmental concentrations (PECs) are less than a factor of 100 or 10 lower than the acute or chronic effect concentrations respectively [toxicity to exposure ratio (TER) <100 or <10], then concerns for aquatic ecosystems are triggered, and further evaluation ('higher-tier risk assessment') of the compound is required. If potential risks are identified, a range of study types may be suitable for addressing concerns, for example, by testing a wider range of species (and then reducing uncertainty factors) or by conducting studies with more realistic exposure regimes. Ultimately, potential concerns can be addressed with field data, in which effects on populations and communities can be measured under more realistic conditions. Here we describe the preliminary risk assessment and the development of higher-tier aquatic data for lambda-cyhalothrin.

The data quoted are taken from extensive studies on lambda-cyhalothrin carried out over the past 14 years. Further details on specific cases may be obtained from the authors.

2 PRELIMINARY RISK CHARACTERISATION FOR LAMBDA-CYHALOTHRIN

Toxicity data used in preliminary risk characterisation include acute and chronic effects on fish and *Daphnia* spp., and studies on algal growth (Table 1). These data demonstrate that lambda-cyhalothrin is highly toxic to fish and aquatic invertebrates in standard, clean-water, laboratory studies. As would be expected for an insecticide, effects on algae are negligible and thus aquatic plants may be excluded from further assessment.

TABLE 1
Acute and Chronic Toxicity of Lambda-cyhalothrin to Aquatic Organisms

Species	*Test duration and type*	*Toxicity*[a] (μg *litre*$^{-1}$)
Daphnia magna Straus (water flea)	48-h immobilization	$EC_{50} = 0{\cdot}36$
Oncorhynchus mykiss Rich. (rainbow trout)	96-h mortality	$LC_{50} = 0{\cdot}24$
Lepomis macrochirus Raf. (bluegill sunfish)	96-h mortality	$LC_{50} = 0{\cdot}21$
Selenastrum capricornutum (green alga)	96-h growth	$EC_{50} > 1000$
Daphnia magna Straus (water flea)	21-d reproduction	NOEC $= 0{\cdot}002$
Cyprinodon variegatus Lac. (sheepshead minnow)	28-d early life-stage	NOEC $= 0{\cdot}25$

[a] EC_{50}—median effective concentration; LC_{50}—median lethal concentration; NOEC—no-observed-effect concentration.

To characterise potential risks, the effect concentration (see Table 1) is divided by a predicted environmental concentration (PEC) in order to develop a toxicity : exposure ratio (TER). In Europe, PECs are currently calculated using relatively simple, worst-case assumptions regarding potential exposure. Initial loadings are generated from spray-drift tables[4] and then deposition onto a 30 cm deep, static water body is assumed to calculate initial exposure concentrations.[3] For a typical arable use of lambda-cyhalothrin, (e.g. 10 g AI ha^{-1}), this results in an initial worst-case concentration of approximately 0·1 μg litre^{-1} in the water column from a single application, assuming a distance between the crop and water body of 1 m. At 5 m distance from the crop, this declines to 0·02 μg litre^{-1}. The TERs for fish and aquatic invertebrates resulting from this initial PEC are less than the trigger values, and so further refinement of the risk assessment is triggered.

3 CONSIDERATIONS FOR REFINING THE RISK ASSESSMENT OF LAMBDA-CYHALOTHRIN

Preliminary risk assessments are intentionally conservative and contain a number of worst-case assumptions and uncertainties that should be refined and tested at the higher tiers of risk assessment if concerns are triggered.

Links between exposure and effect concentrations

Standard laboratory studies artificially maintain exposure concentrations throughout the duration of the study and do not incorporate factors which may influence exposure under field conditions. For example, many pesticides degrade or dissipate rapidly under natural conditions, and if this occurs at time intervals shorter than the standard toxicity studies, potential for effects under field conditions may be significantly overestimated.

Sensitivities of aquatic organisms

The preliminary assessment TER trigger values of 100 and 10 include uncertainty regarding the relative sensitivities of the standard test organisms compared to the range of species present in the field. This safety factor assumes that there may be organisms exposed which may be up to 100 or 10 times more acutely or chronically sensitive, respectively, than the standard test organisms (rainbow trout and *Daphnia* sp).

Ecological relevance of effects

Ecologically important processes such as recovery through reproduction and re-invasion or avoidance of pesticides (which may be important for highly mobile organisms such as fish) are not included in the standard laboratory toxicity data used in preliminary assessments. These may substantially modify effects on ecosystems under natural conditions.

In order to refine the risk assessment, the potential influence of each of these factors should be considered. In the remainder of this paper we describe such considerations for lambda-cyhalothrin. It should also be noted that the calculation of PECs is also a major uncertainty in the risk-assessment process because again a number of worst-case assumptions are made, e.g. that every application will result in substantial spray drift deposited on watercourses that are shallow and static with no interception of drift between the crop and the water body. It is also possible to refine each of these assumptions, but this will not be addressed in this paper, the focus of which is on refinement of the effect concentrations.

4 LINKS BETWEEN EXPOSURE AND EFFECTS

4.1 Exposure and effects in the water column

For lambda-cyhalothrin and other pyrethroids, it has been widely recognized that their properties (especially their rapid and substantial adsorption to plants, sediments and organic matter) would lead to significant reductions in exposure in the water column and hence potential risk under more natural conditions. For lambda-cyhalothrin, the dissipation rate (DT_{50}) from water in a laboratory water-sediment system is only 5–11 h, indicating that concentrations in water in natural systems will be negligible within a short period of time. Consequently, risk assessments for water-column organisms based on initial concentrations in the water body compared to standard constant exposure periods in laboratory tests (e.g. 48 and 96 h for *Daphnia* sp and fish acute studies, respectively) may greatly overestimate the actual risk.

The rapid dissipation of lambda-cyhalothrin is also important for considerations of chronic exposure and toxicity. With a short water half-life, the dissolved concentration of the chemical will rapidly decline, so chronic concerns (the effects of long-term exposures), or those resulting from multiple applications (potential for build-up from several applications) are not applicable. Consequently, risks from use of lambda-cyhalothrin will be dominated by acute exposures and effects. The only potential chronic concerns are for sediment-dwelling organisms where chronic exposure may occur. (See section 4.2 below).

In order to address exposure uncertainties, two issues need to be considered:

- to what extent is apparent toxicity reduced by more realistic exposure (as influenced by physicochemical and fate properties)?
- what is the potential effect of short-term exposures—does a 1-h exposure have the same effects as a 96-h exposure?

4.1.1 Modified exposure studies

The first of the aforementioned considerations has been investigated in studies in which the exposure regime of standard toxicity studies has been modified to simulate exposure in the environment more realistically. In one study, *Daphnia magna* Straus and *Cyprinus carpio* L. were exposed to cyhalothrin (the unresolved form of which lambda-cyhalothrin is one of the paired isomers) in static water systems in which there was soil.[5] Three application methods were used:

1. application to the water phase (i.e. crudely simulating spray drift);
2. application to the water phase after stirring (i.e. crudely simulating spray drift when suspended sediment is present);
3. application to the soil before adding water (i.e. broadly representative of lambda-cyhalothrin that has reached a water body through runoff).

Each method demonstrated a reduction in toxicity from that observed in water-only studies (Table 2), indicating that, under environmentally realistic conditions, exposure will be substantially reduced, thereby reducing apparent toxicity of the compound.

A similar study has been conducted with lambda-cyhalothrin and *D. magna* using two aquatic sediments and a soil. First-instar *Daphnia* were exposed to lambda-cyhalothrin for 72 h in water alone, and in

TABLE 2
Reductions in Observed Toxicity of Lambda-cyhalothrin to *Daphnia magna* and *Cyprinus carpio* in Water–Sediment Systems

	Reduction factor of toxicity relative to water-only study	
Exposure route	Daphnia magna	Cyprinus carpio
Applied to water phase	3	4
Applied to water phase after stirring	40	7
Applied to sediment prior to addition of water	175	74

water-sediment systems that were either stirred or left unstirred. In this study, there was an even greater reduction in the observed toxicity in the presence of sediment (between 73 and 280 times), and there was little difference between stirred and unstirred systems (Table 3).

4.1.2 *Effects of short-duration exposures*

The second of the aforementioned considerations for refining the risk assessment has been addressed by examining the influence of short exposures on the effects of lambda-cyhalothrin with the freshwater amphipod (shrimp), *Gammarus pulex* L., which is among the most sensitive of the organisms tested (see section 5 below). In this study, *G. pulex* were exposed to test concentrations of lambda-cyhalothrin for 1, 3, 6, 12 and 96 h. After exposure, organisms were returned to clean water and the numbers affected were recorded at 96 h. There was a highly significant relationship between the exposure duration and the effect concentration (Fig. 1), with exposure of 1 h being some 18 times less toxic than those of 96 h. Similar results have been observed for another amphipod, *Hyalella azteca* (Saussure), with the pyrethroid cypermethrin (Fig. 1).

TABLE 3
Comparison of Toxicity of Lambda-cyhalothrin to *Daphnia magna* in the Presence and Absence of Sediment (Stirred and Unstirred)

Test system	LC_{50} (μg $litre^{-1}$) *Unstirred 72 h*	*Stirred 72 h*	*Ratio sediment present: water alone:* *Unstirred*	*Stirred*
Water alone	0·26	—	—	—
Sediment 1	31	21	120	81
Sediment 2	63	72	240	280
Soil 1	19	20	73	77

The above studies have shown that exposure of aquatic organisms under field conditions will be significantly reduced through adsorption to sediment, and that the duration of exposure will be much less than under standard 'clean water' test conditions. In combination, these two factors suggest that risks to fish and invertebrates in the water column will be significantly lower than those determined from standard worst-case assessments.

4.2 Exposure, bioavailability and effects in sediments

Since lambda-cyhalothrin adsorbs to sediments, is moderately persistent in soil and sediment, and is relatively toxic to aquatic invertebrates, evaluation of the potential risks to sediment-dwelling (benthic) organisms is also required.[6] A number of studies have been conducted to assess the bioavailability and toxicity of lambda-cyhalothrin in sediments.

4.2.1 *Bioavailability*

The bioavailability of [^{14}C]lambda-cyhalothrin and its bioconcentration by sediment-dwelling larvae of the midge, *Chironomus riparius* Meig., has been studied in laboratory water–sediment systems (10 g dry weight sediment : 250 ml water) using 10 different sediments (two replicates per sediment) possessing a wide range of physicochemical properties. The chemical was applied to a sediment slurry, mixed, and after an equilibration period, ten fourth-instar *C. riparius* larvae were introduced into the test system and exposed for 48 h under

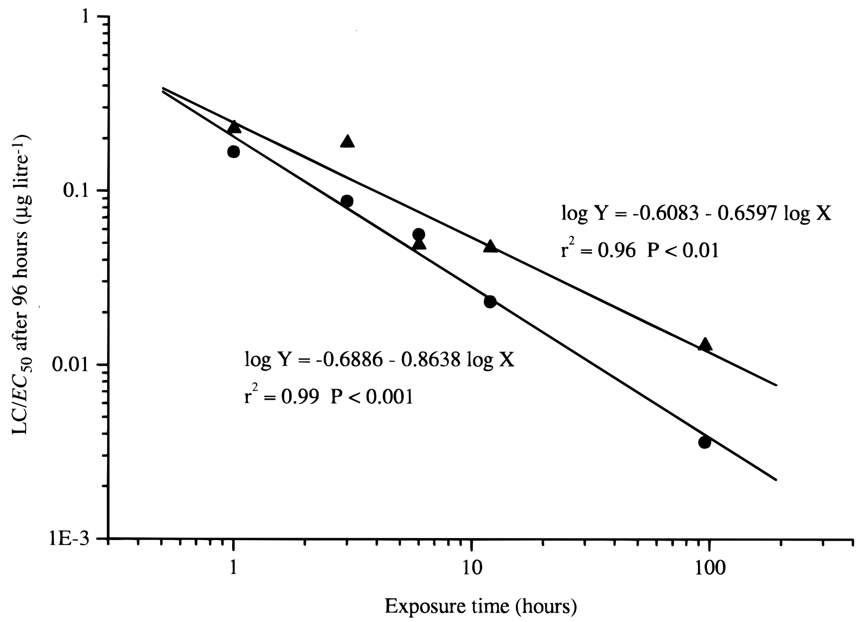

Fig. 1. Relationship between exposure duration and toxicity at 96 h for (▲) lambda-cyhalothrin and *Gammarus pulex*, and (●) cypermethrin and *Hyalella azteca*.

static conditions. After this time, the partitioning of the chemical between sediment, water and organism phases was determined. In addition, bioconcentration in water alone for a similar exposure duration was also investigated.

In all sediment–water test systems, more than 99% of the lambda-cyhalothrin was adsorbed to the sediment, as would be expected. Aqueous-phase concentrations varied depending on the organic carbon (OC) content of the sediment, with more chemical in the water phase at lower levels of OC. Bioconcentration factors (BCFs) from the sediment–water systems (concentration in the organism divided by concentration in the exposure phase) were very consistent when expressed as water-phase exposure concentrations, and ranged from 1300 to 3400 (mean of 2300). These were also very similar to the BCF measured in water-only systems of 2000. BCFs expressed as sediment-phase exposure concentrations were always less than 1 (range 0·11 to 0·84). There was a consistent inverse relationship between the proportion bound to the sediment (K_d = concentration in sediment divided by concentration in water) and the sediment BCF (Fig. 2), indicating that the higher the proportion of the chemical that was adsorbed, the lower the amount that was bioavailable. Overall, these data demonstrated that lambda-cyhalothrin adsorbed to sediment would be of low bioavailability to benthic organisms and supported the application of Equilibrium Partitioning Theory[7] to the sediment bioavailability of lambda-cyhalothrin.

4.2.2 *Toxicity to benthic organisms*

Two studies have been conducted to determine the toxicity of lambda-cyhalothrin to sediment-dwelling organisms, with each study utilising a different exposure route. In the first study, which followed the German BBA toxicity test guidelines,[8] *C. riparius* were added to laboratory water–sediment systems (266 g dry weight sediment and 2·6 litres of overlying water) and test chemical was applied to the water phase with the organisms present. This crudely simulates a spray-drift entry route and subsequent exposure initially through the overlying water phase (*Chironomus* irrigates its dwelling tube with overlying water so that exposure is also possible through this route). A range of concentrations from 0·16 to 5·0 µg litre^{-1} were applied and test systems were observed for emergence for 28 days after application. Based on the concentrations applied to the water at the start of the study, the EC_{50} based on total emergence (i.e. a 50% reduction in emergence relative to the control) was 2·4 µg litre^{-1}. The no-observed-effect concentrations were 0·62 µg litre^{-1} and 0·16 µg litre^{-1}, based on total emergence and time to emergence, respectively. Comparison of these to other chronic studies on invertebrates shows that risks to sediment-dwelling organisms are substantially less than those for water-column organisms. Comparison of the EC_{50} in this study to the 48-h EC_{50} in water alone (2·4 µg litre^{-1}—see Table 5) further demonstrates that the effects observed in this study were associated with initial exposure via the water column.

Although the BBA toxicity test can provide data which can be compared to initial water column concentrations, methods which spike the sediment[9] are probably more appropriate for determining chronic, long-term risks from sediment residues. The toxicity of sediment-associated lambda-cyhalothrin residues has been investigated in a study on the emergence of *C.*

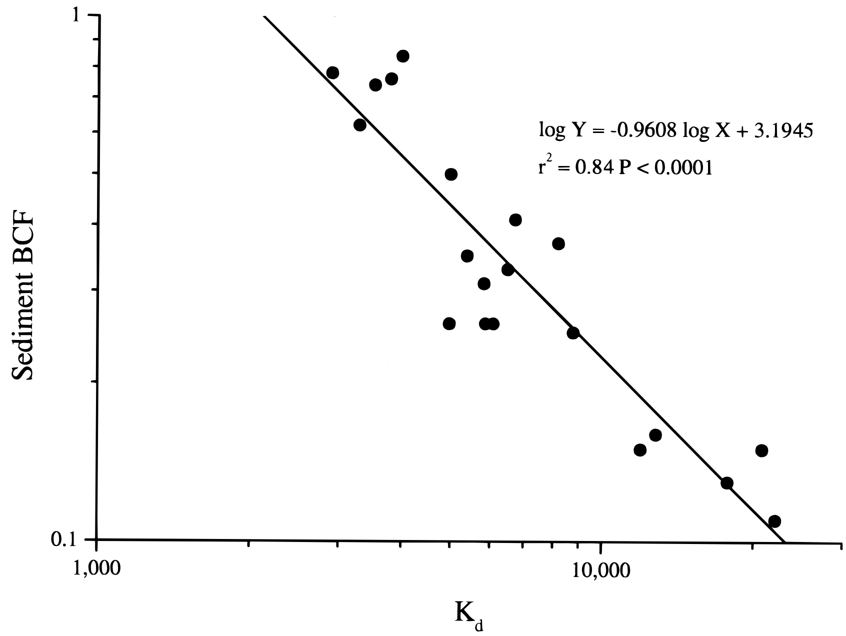

Fig. 2. Relationship between sediment adsorption coefficient (K_d) and sediment bioconcentration factor (BCF) for *Chironomus riparius* larvae.

TABLE 4
Acute Toxicity of Lambda-cyhalothrin to Additional Species of Fish

Species	*96-h LC_{50} (μg litre^{-1})*
Gasterosteus aculeatus L. (three-spined stickleback)	0·40
Oryzias latipes (Japanese rich fish)	1·4
Ictalurus punctatus Raf. (channel catfish)	0·16
Brachydanio rerio Hamilt & Buch. (zebra danio)	0·64
Poecilia reticulata Peters (guppy)	2·3
Leuciscus indus (L.) (golden orfe)	0·078
Pimephales promelas Raf. (fathead minnow)	0·70
Cyprinus carpio L. (mirror carp)	0·50

riparius. In this study, test systems consisted of 500-ml glass vessels containing 30 g dry weight of sediment and 250 ml of water. Test systems were dosed in the range 62 to 2000 μg kg^{-1} sediment by applying lambda-cyhalothrin to the water–sediment system, shaking and then rolling for two hours. After allowing the system to settle for two days, first-instar *C. riparius* larvae were introduced into the test systems. Observations were made daily for emergence up to 28 days. Based on measured concentrations in the sediment at the start of the test, the EC_{50} on emergence was 250 μg kg^{-1} and the NOECs were 105 and 213 μg kg^{-1} based on total emergence and time to emergence, respectively.

In order to determine the potential for risk to benthic organisms, it is necessary to estimate exposure concentrations in the sediment. Conservatively assuming that 100% of the lambda-cyhalothrin partitions from the water column into the top 5 cm of sediment (bulk density 1·3 g cm^{-3}), and assuming a total drift exposure probability of 95% for multiple applications, 28-day average sediment concentrations for European arable uses of lambda-cyhalothrin will be approximately 0·5 μg kg^{-1} (assuming a minimum distance between crop and water of 1 m). Comparing this to the toxicity values described above indicates a factor of more than 10 between effect and exposure concentrations, indicating negligible risks to benthic organisms.

5 SENSITIVITIES OF AQUATIC ORGANISMS

As discussed above, a major component of the uncertainty in preliminary assessments of aquatic risk is the potential difference in sensitivity between standard test species and the range of species which may occur in nature. In order to explore these potential differences for lambda-cyhalothrin, additional acute toxicity tests have been conducted on a range of fish and aquatic arthropods (the invertebrate group most sensitive to pyrethroids). Appropriately, acute studies were conducted, since short-term water-column exposure is most consistent with the likely pattern of environmental exposure—as discussed above; standard chronic studies were judged to be of limited application to higher-tier risk assessment. The methods used in the studies (96-h mortality for fish, 48-h immobilisation for invertebrates)

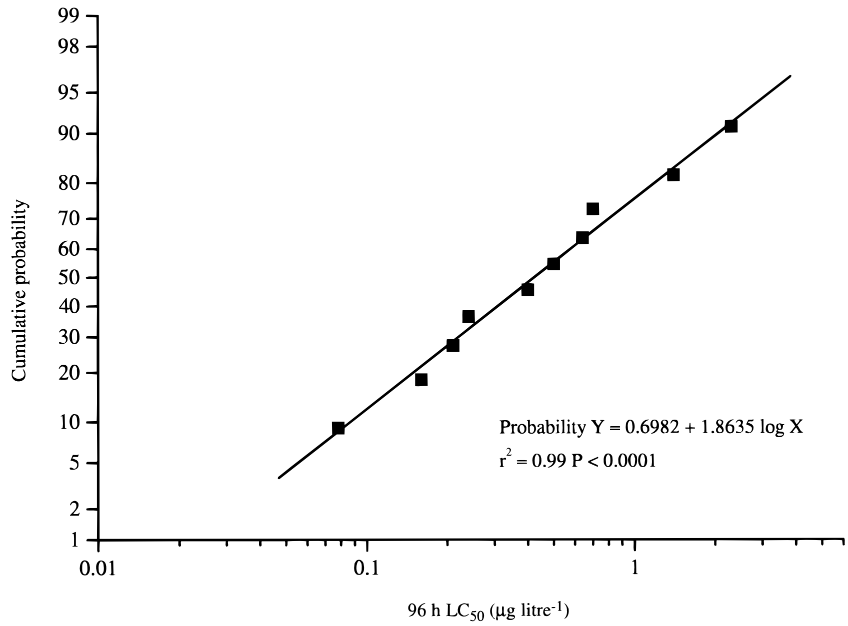

Fig. 3. Probabilistic distribution of fish acute toxicity data.

TABLE 5
Acute Toxicity of Lambda-cyhalothrin to Species of Freshwater Arthropods

Organism	EC_{50} (*μg litre*$^{-1}$)
Hyalella azteca (freshwater shrimp)	0·0023
Chaoborus sp. (phantom midge larva)	0·0028
Gammarus pulex L. (freshwater shrimp)	0·014
Asellus aquaticus (water hoglouse)	0·026
Corixa sp. (water boatman)	0·030
Cloeon dipterum (mayfly nymph)	0·038
Hydracarina (water mite)	0·047
Ischnura elegans (damselfly nymph)	0·13
Cyclops sp. (cyclopoid copepod)	0·30
Chironomus riparius (midge larva)	2·4
Ostracoda (seed shrimp)	3·3

were similar to those employed in standard acute toxicity studies.

5.1 Data on additional fish species

Data on eight additional species of freshwater fish have been generated, as well as the standard regulatory data on rainbow trout and bluegill sunfish (Table 4). Of the total number of fish tested, the most sensitive was the golden orfe, with a 96-h LC_{50} of 0·078 μg litre^{-1}. Since the most sensitive fish species in the base data set (bluegill sunfish with a 96-h LC_{50} of 0·21 μg litre^{-1}; Table 1) is only two to three times less sensitive, it can be concluded that the distribution of fish sensitivity to lambda-cyhalothrin is narrow. In this case, it would be appropriate to lower the TER trigger values used in the preliminary assessment.

Since the selection of test species could be viewed as somewhat arbitrary, a more formal statistical analysis of the distribution of fish toxicity data is possible to describe the cumulative probability distribution of effect concentrations.[10] Cumulative ranked probability (based on normalised ranked fish toxicity values) is plotted against log effect concentrations to indicate the likely probability of effect concentrations being exceeded at various concentrations (Fig. 3). The effects of lambda-cyhalothrin on fish fitted this log-normal model well, so that estimates of cumulative likelihood of effect can be made with confidence. To describe these distributions and evaluate potential effects, the effect concentration (X axis) which affects a certain proportion of species (Y axis) can be estimated from the fitted regression line. Previous studies with pyrethroids[12] and other chemicals[13] have shown that the 10th percentile effect concentration (based on 96-h LC_{50}) is protective of fish populations and invertebrates communities in field studies. The 10th percentile for lambda-cyhalothrin is 0·087 μg litre^{-1}.

5.2 Data on additional arthropod species

Since arthropods are known to be the organisms most sensitive to pyrethroids, additional acute toxicity data have also been generated for a wide range of freshwater arthropod species (Table 5). By including *D. magna* data (Table 1), a total of 12 species of arthropod have been tested with lambda-cyhalothrin. The range of sensiti-

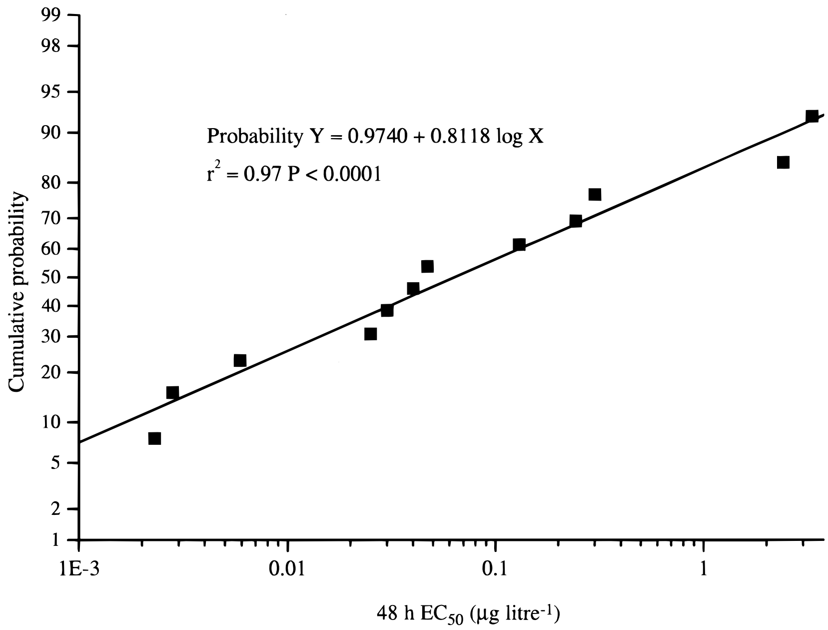

Fig. 4. Probabilistic distribution of arthropod acute toxicity.

vities of arthropods is greater than that for fish; amphipods and isopods were approximately 100 times more sensitive to lambda-cyhalothrin than *D. magna.*

As with fish, these data can be used both to reduce the TER trigger applied to the preliminary risk assessment or to develop probabilistic effect distributions (Fig. 4). The 10th percentile (protective of effects in the field) for this distribution was 0·0017 μg litre^{-1}.

6 ECOLOGICAL RELEVANCE OF EFFECTS

Field studies with pesticides can be useful for putting effects measured in laboratory studies into an ecological context, particularly because they include many of the important ecological processes which can be difficult to include in laboratory studies. Most important, perhaps, field studies allow evaluation of effects at the community level for certain assemblages of organisms (e.g. phytoplankton, zooplankton, macroinvertebrates), and often this is an important endpoint of the risk assessment. Another advantage of these studies is that exposure is generally more realistic than in laboratory studies.

In the case of lambda-cyhalothrin, additional laboratory data have shown that, although reduced exposure resulting from the presence of sediment mitigates concern, several important groups of invertebrates (e.g. amphiphods, isopods) are particularly sensitive, so it may be important to establish the influence of potential effects on these groups on freshwater communities. For fish, it is more difficult (if not impossible due to size constraints) to study communities (i.e. assemblages of species) in replicated field studies, so additional field data can only provide further confirmation that reduced exposure will result in reduced impacts and potentially include such behavioural aspects as avoidance. In general, studies with fish are better conducted in the laboratory where more experimental control is possible. Three aquatic field studies have been conducted on lambda-cyhalothrin: a mesocosm study in 25-m^3 ponds in the UK, a US mesocosm study in 450-m^3 ponds, and a fish–rice culture study in the Philippines.

6.1 UK mesocosm study

Full details of the study are reported by Farmer *et al.*[11] Two treatments of lambda-cyhalothrin at spray application rates of 1·7 and 0·17 g AI ha^{-1} were applied four times at two-week intervals to 25-m^3 ponds. Assuming full mixing throughout the water column, this was equivalent to initial nominal concentrations of 0·17 and 0·017 μg litre^{-1}. Fish were not studied.

At the higher application rate, there were initial transient effects on certain insect species, but recovery was rapid. There were also effects on amphipods and isopods from which little recovery had occurred by the end of the study. At the lower rate, there were negligible effects on insects or isopods, but there were still effects on the Gammaridae. Although recovery of the Gammaridae had not occurred by the end of the study, the closed-off nature of the test system did not include the possibility for recovery by normal life-history processes (e.g. drift and recolonisation by swimming and scrambling). Under more natural ecological conditions, recovery at this treatment rate would have been expected through recolonisation. Similar conclusions have been drawn for the pyrethroids cypermethrin and esfenvalerate in mesocosm studies.[12] Indeed, observations of field populations of Gammaridae have shown rapid recovery after pyrethroid exposure.[14,15]

Analysis of the invertebrate community structure (Fig. 5) was performed using the recently developed Principal Response Curves method.[16] This method generates a statistic which is derived from abundances of all species. Comparison of the statistic from control and treatments allows the determination of effects at the community level. PRC analysis showed only minimal differences in community structure at the lower treatment rate, but more substantial changes in community structure at the higher treatment rate. This suggests that the overall impact on the ecosystem at the lower treatment rate is small. The ‘no observed adverse ecological effect concentration’ (NOAEC) from this study was therefore judged to be 0·017 μg litre^{-1}.

6.2 US mesocosm study

The detailed results of the study are reported by Hill *et al.*[17] Treatments of the ponds included 12 simulated spray drift events and six simulated runoff (slurry) events at three treatment rates. The low rate received 12

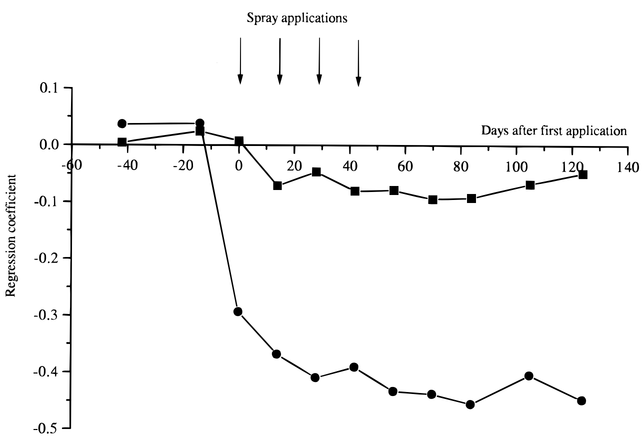

Fig. 5. Principal response curves for macroinvertebrate communities in the UK mesocosm study. The X-axis represents the control community throughout the study (normalised for temporal changes) and deviations from this indicate a change from the control community structure due to treatment. —■— Low treatment (0·17 g AI ha^{-1}). —●— High treatment (1·7 g AI ha^{-1}).

sprays of 0·017 g AI ha^{-1} (nominally 0·0017 μg litre^{-1} assuming mixing throughout the water column) at weekly intervals, and six slurry applications of 0·05 g AI ha^{-1} at two-week intervals (nominally 0·005 μg litre^{-1} assuming even mixing throughout the water column). The medium and high rates had 10 and 100 times the low-rate applications on the same schedule.

Bluegill sunfish were stocked in the ponds. Results for invertebrates were similar to those obtained in the UK study. There were only minor and transient effects on invertebrates at the low and medium treatment rates. More substantial effects were seen on invertebrates at the high treatment rate, particularly on planktonic crustacea and insects, but in many cases, there was recovery by the end of the study. No adverse effects on fish were observed in any of the treatments.

The use of these treatment regimes in risk assessment can be complicated because the study was attempting to mimic a particular scenario. However, assuming that much of the lambda-cyhalothrin run-off was unavailable, it is probably not unreasonable to use the nominal initial exposure concentration from a single application as a conservative estimate of the effect concentration in the study. Consequently, from an ecological perspective, the NOAEC for invertebrate communities was 0·017 μg litre^{-1}. For bluegill sunfish, the no observed effect concentration was $\geqslant$0·17 μg litre^{-1}.

6.3 Philippines fish–rice culture study

The details of this study are described by Hamer *et al.*[18] In this study, rice paddies containing Nile tilapia (*Tilapia nilotica*) were treated at up to 25 g AI ha^{-1}, which is equivalent to 25 μg litre^{-1} in a 10-cm-deep rice paddy, although again it is difficult to relate these exposure regimes to one particular concentration. No effects were observed on fish mortality, growth or production at any of the treatment rates. The study is clearly a special case of a very specific use of lambda-cyhalothrin, but the data do demonstrate that even when concentrations approach or exceed water solubility, adverse effects on fish are unlikely.

7 CONCLUSIONS

Although preliminary risk assessments identify potential concerns for fish and aquatic invertebrates, a large amount of ecotoxicity data is available to refine the aquatic risk assessment of lambda-cyhalothrin. These data show that when more environmentally realistic exposure conditions are taken into account, potential risks from pyrethroid uses are substantially reduced. Adsorption of lambda-cyhalothrin to sediments leads to significant reductions in bioavailability, and, when adsorbed, the compound does not present any potential risks to sediment-dwelling organisms.

Analysis of a range of fish toxicity data shows that sensitivities of fish species are very similar, justifying a reduction in the TER trigger values for this phylum. Field studies have demonstrated that effects on fish are unlikely under more realistic conditions. Toxicity data on a range of arthropod species show that the Crustacea and Insecta are the more sensitive taxonomic groups. Whilst this may lead to some effects under field conditions, recovery potential of these groups is large, and field data generally show that any effects are likely to be transient.

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